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Communicating Commander's Intent in a Chain of Command With Multi-Criteria Decision Analysis—An Experiment in Air Combat

Kai Virtanen[1,2] | Heikki Mansikka[1,2] | Mikko Kankaisto[3] | Raimo P. Hämäläinen[1]

[1]Systems Analysis Laboratory, Department of Mathematics and Systems Analysis, Aalto University, Espoo, Finland | [2]Department of Military Technology, National Defence University, Helsinki, Finland | [3]Finnish Air Force, Tikkakoski, Finland

Correspondence: Kai Virtanen (kai.virtanen@aalto.fi)

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ABSTRACT

Decision making in a chain of command with a rapid time frame is typical in military and emergency contexts, and yet the topic has received almost no attention in the MCDA literature. The commander's intent regarding the implementation of an operation is expressed at the top level of the command chain. Before the intent is put into practice, it must be passed through different levels of the chain. Typically, the intention statement does not provide exact guidance on how the operation should be planned and executed on the lower levels. As a result, behavioural effects and biases can distort the interpretations of the intent at the lower levels. The contribution of this paper is an approach for using MCDA to support communication, planning and decision making in the chain of command. In this approach, criteria weights of an MCDA model are determined on the highest level by the commander. Then, the commander's intent is communicated so that the message from the top level also contains these weights, and the MCDA model is utilised on the lower levels. The approach was evaluated in an air force test case. Two air force commanders expressed their intents and corresponding criteria weights for two defensive counter air operations. The criteria were related to the survival of own aircraft, the destruction of enemy aircraft and the expenditure of missiles. The commanders used five weighting methods, that is, SMARTER, Direct, Swing, SMART and AHP. They preferred the Direct and Swing methods. Air force staff officers planned the air operations by following the standard and MCDA-supported planning procedures. The simulation of these operations revealed that the MCDA-supported ones were in better compliance with the commanders' original intent statements. Thus, the MCDA approach appeared to support the integrity of the command chain as the intent was conveyed through it.

1 | Introduction

The multi-criteria decision analysis (MCDA) literature has, so far, focused on decision making in organisational settings where there is time to analyse a decision-making situation iteratively with the decision makers and stakeholders. That, however, is not always the case in planning and decision making. Decision making in a chain of command (e.g., Matyja and Rajchelt-Zublewicz 2020; see also https://www.organimi.com/chain-of-command-in-business), where the initial decision is made at the highest level and is then passed down through the lower levels of the command chain for further refinement, is an important uncharted territory for MCDA scholars. In such cases, decisions and planning are made without immediate feedback from the lower to higher levels of the chain. This type of decision making can be related to time restricted situations or the organisational structure in place. For instance, in a military context, decisions are typically expressed in the form of orders. By their very nature, orders leave little or no room for debate or iteration between the level giving the order and the one receiving it. Besides the military, chain of command structures are also found in many crisis and emergency situations where one does not have time to evaluate and reflect on the choices iteratively, see, for example, Launder and Penney (2023).

In a chain of command setting, the top-level decision maker is often called a commander. The commander can be the chief of a fire brigade in a forest fire or a military commander who faces a challenge in deciding how to express her/his intention in a complex operation without the possibility to evaluate the decisions and plans made on the lower levels before they are executed. Rather than giving detailed instructions and guidance on how actors on the lower levels should operate, it is often better to communicate the commander's intent in a general way and give the lower-level actors autonomy in choosing details of the operation plans as well as in selecting how to execute them. In complex military operations, such a planning procedure has always been the established tradition.

Behavioural impacts are naturally brought into the foreground in chain of command settings. When an intention statement is interpreted and re-sent repeatedly in a chain of actors, there is a risk that the message becomes distorted. Cognitive biases have received a lot of attention in the MCDA literature (e.g., Montibeller and Von Winterfeldt 2015). Biases are present in emergency decision making too (D'Alessio et al. 2024) and the generation of policy alternatives can be affected by behavioural effects (Hämäläinen et al. 2024). Biases can also emerge in communication processes and occur in a chain of command -style decision making. In such settings, stress and time pressure are often present and may impair decision making (see, e.g., Maule and Svenson 2013). Typical behavioural and cognitive biases include the framing effect where the way information is presented influences how it is perceived, and the availability heuristic where the perceived frequency or importance of an event is influenced by how easily it comes to mind. Also, the confirmation bias causes people to seek out information that supports their pre-existing beliefs. As a result, parts of the message's original intent may be lost in a chain of communication.

Minimising the aforementioned issues in communication presents a significant challenge. Improving interpersonal communication skills and practices could be one approach. There is evidence in the decision analysis literature that training is not very efficient in avoiding biases in decision contexts (Hämäläinen and Alaja 2008; Ferretti et al. 2023). In a setting where actors on different levels of a chain of command can come from different backgrounds, guaranteeing that training will be successful is likely to be difficult. Another approach to eliminate biases in decision making is to change or modify the communication or decision-making procedure. For an example application of this idea in preference elicitation, see Lahtinen et al. (2020). Following the idea of changing the procedure, we suggest changing the way the message itself is transmitted through a chain of command. So, rather than imposing changes in people's behaviour we propose a change in the structure of the communication procedure.

A written description of an intent given by a commander on the top level of a command chain can be interpreted in different ways by actors on the lower levels. In the new MCDA approach suggested in this paper, the main idea is to change the structure of the message communicated and transmitted through the command chain. Rather than using a written description only, the intent is expressed so that the message also includes weights of decision criteria included in an MCDA model. The commander determines criteria weights in connection with the expression of the intent. Then, the MCDA model with these weights is used for supporting communication, planning and decision making on the lower levels of the chain. In general, different kinds of MCDA models could be used for this purpose, reflecting the broad evolution of MCDA methods and approaches to preference modelling (see, e.g., Greco et al. 2025). We demonstrate the use of the MCDA approach in a test case regarding air operations. In this paper, we use the popular value tree method (Belton and Stewart 2002) in its simplest form with only one level of criteria. As a result, the effort in modelling is relatively simple including the identification of objectives and criteria, forming action alternatives and the evaluation of value scores of these alternatives. This MCDA format is easy to understand and work with, and the weights of the criteria can be easily transmitted to all levels of the chain of command. Our core hypothesis is that when the actors in the command chain adopt such a communication format, it will reduce the risks of misinterpretation and will result in actions that better reflect the commander's original intent.

The literature on the communication of intent extends from the management studies on the implementation of company strategies (see, e.g., Shimizu 2017) to studies on decisions involving a chain of command. In this paper, we focus on the latter ones. Chain of command structures are used often in time limited situations like emergencies. In the literature, these structures are mostly considered in military applications (see, e.g., Farley and Stouffer 2008). Different aspects and the effectiveness of commanders' intent expressions are studied, for example, by Lindoff et al. (2006) and Lif et al. (2010). Many challenges have been identified regarding chain of command type decisions. For example, Shattuck and Woods (1997) observed that company commanders in the army failed to follow their battalion commander's intent. In their later study (Shattuck and Woods 2000), similar failures in communicating intent were again observed and communicating with the path focus is suggested as a possible improvement. Hayne et al. (2013) found that it can be beneficial to include a strong expression of the objective of an operation in the intention statement. Shattuck (2000) concluded that commanders should explain the reasoning behind the decisions reflected in their orders. The MCDA approach presented in this paper offers one way of giving such a rationale. Winner et al. (2007) suggested that improvements in communication can be achieved by expressing commanders' values explicitly in their intention statements. This idea is in line with our approach since criteria weights reflect the values of the commander. It is interesting to note that Guitouni et al. (2008) included an MCDA module in the commander's decision support system used to design actions in preventing airspace violations. Duško and Bozanic (2023) have also presented an MCDA model for combat situations, and Mansikka et al. (2021a, 2021b) have introduced a multi-criteria approach for testing and evaluation of air combat tactics, techniques and procedures. However, these studies do not consider using MCDA in a chain of command type planning. The role of situational awareness in understanding communication is emphasised by Thomas et al. (2007). The same topic is also related to coordination efforts of teams (Mansikka, Virtanen, et al. 2023; Mansikka, Harris, et al. 2023).

One suggested method for conveying the commander's intent and ensuring its correct interpretation is back briefing (Howard 2000). The idea is that a lower-level actor tells a higher-level actor how she/he has understood the received task and how she/he intends to carry it out. This method is suitable for use between two levels. If the method is to cover the entire command chain, it may take too long to convey the message from the commander to the actors of the lowest level. Moreover, back briefing does not eliminate the possibility that the actors on each level may cumulatively distort the message—an issue mitigated by our MCDA approach.

In addition to the MCDA papers discussed above, there are a large number of papers on the application of MCDA in various military contexts (e.g., Burk and Parnell 2011; Costa et al. 2022; Vanzetta et al. 2024; Petropoulus et al. 2024). The literature on MCDA applications in other contexts is extensive (e.g., Belton and Stewart 2002; Linkov et al. 2021). This literature mainly considers the use of MCDA in organisational planning and resource management often with collaborative and iterative settings for model development and actual decision making. Such settings differ essentially from the chain of command structure, where collaborative feedback and iteration are usually not feasible. This paper addresses a previously unexplored problem area for MCDA, that is, decision making within the chain of command. To summarise our methodological contribution, we propose an approach in which MCDA criteria weights are used as explicit components of the commander's intent, thereby improving the clarity and precision of communication throughout the command chain. This innovation offers a structured protocol for embedding MCDA in such a chain, a topic not previously examined in the literature.

The practical applicability of the new MCDA approach suggested in this paper needs to be tested in a realistic environment. We studied the use of the approach in an air force test case. First, an MCDA model for supporting planning of defensive counter air (DCA) operations in the actual chain of command was developed. A group of air combat experts was involved in the model development phase. In the decision analysis phase of the approach, two air force commanders expressed their intents and weighted criteria in two DCA operations. The criteria were related to survival of own aircraft, kill of enemy aircraft and expenditure of own air-to-air missiles. The commanders used five weighting methods: SMARTER based on rank ordering of criteria only, Direct, Swing, SMART and pairwise comparisons of AHP (Belton and Stewart 2002). Courses of actions (COAs) for the DCA operations were identified following both the standard and MCDA-supported planning procedures. The decision makers were true actors and operators in the realistic chain of command environment, that is, staff officers of the Finnish Air Force. The resulting COAs were evaluated and compared in an air combat simulation experiment. For the sake of brevity, a detailed description of the test case is not included in this paper, but it is available in Finnish in the thesis of Kankaisto (2023). Despite being based on simulations the test setting was realistic. The simulation environment used in the test case is also employed in the training of military staff, including aircraft pilots, as well as in the development of air combat tactics, techniques and procedures.

The testing of the MCDA approach was motivated by the following research questions. First, was the approach acceptable to the commanders and how did they find the weighting of criteria and what were the thoughts of the military staff when the approach was used? Second, did the MCDA-supported planning procedure result in acceptable COAs and how did these COAs compare with those obtained by the standard planning procedure? The answers to these questions were positive. In the following sections of the paper, the MCDA approach and the air force test case are described in more detail.

2 | The MCDA Approach in a Chain of Command

There are different contexts where a chain of command is the organisational standard used for decision making. Decision support in these contexts is problematic if there is no time or possibility to get feedback upwards in the chain to evaluate impacts of decisions made on the lower levels of the chain. On the top level, it is typical for the commander to express her/his intent broadly only by outlining the key goals and principles to be followed. Going into details would be a challenging task for the commander especially when a decision-making situation is complex and evolves dynamically. Moreover, figuring out the commander's core message in such an extensive intention statement would also be overwhelming to receivers on the lower levels of the command chain.

When the commander expresses her/his intent in a general fashion by using words, there is a risk that each lower level interprets it in different or erroneous ways. In the MCDA approach suggested here, the goal is to keep the core of the intent intact by expressing it also in the form of criteria weights of an MCDA model. Using the weights as a part of the message from the upper level to the lower levels is a way of minimising misinterpretations and distortions of the intent. It should be noted that our basic idea is not restricted to any MCDA modelling method. In our demonstration case, we use the easy to understand and widely used value tree analysis with an additive value function. Other MCDA methods could be used too, but to demonstrate this new idea to a general audience, we chose to work with the simple value tree model.

We consider a generic chain of command, comprising command, planning, control and execution levels, as illustrated in Figure 1. Such a structure can be found across various application areas. Naturally, the names of the levels may vary in each area, and the command structures have distinctive characteristics. For example, in a military context, the levels are often called strategic, operational and tactical. In the first phase of the approach, MCDA models are constructed. The second phase is the decision analysis part in which the models are utilised for supporting communication, planning and decision making in the command chain. There can be two different MCDA models as presented in Figure 1, that is, one for the command and planning levels and another one which has a more detailed structure for the planning and control levels. In some cases, a single model for both levels could be sufficient. It should be noted that in the

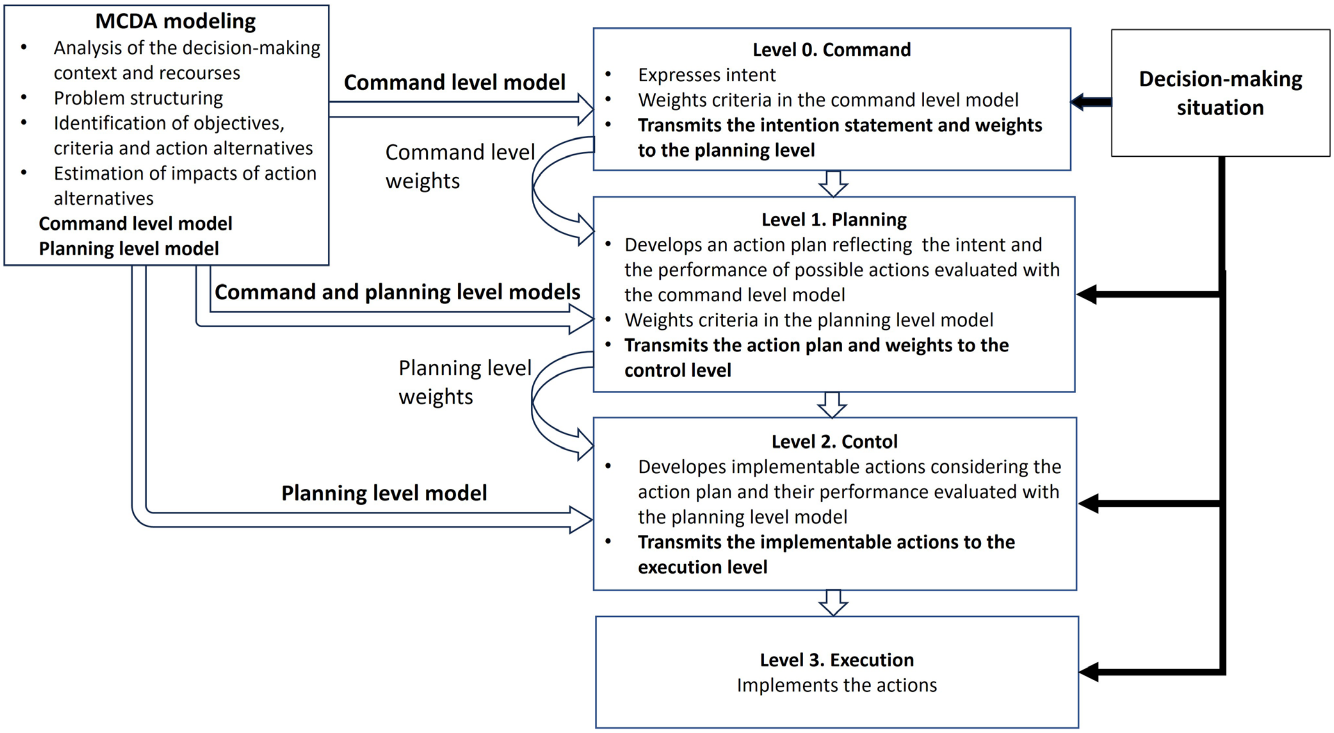

FIGURE 1 | The MCDA approach for supporting communication, planning and decision making in a chain of command.

real world there are often more than one actor or operator with different areas of responsibility on the planning, control and execution levels.

The modelling phase needs to be carried out in advance for the decision-making context under consideration. Advanced modelling is typically required, as there may not be sufficient time for this phase once the decision situation begins to evolve. In practice, there can be different ways of carrying out the modelling phase. In some settings, the leadership can develop models for predefined contexts. Sometimes it may also be possible to work on the models closer to the time when the incident is expected to happen.

The modelling phase includes problem structuring and gathering of data with experts. The resources available for conducting the operation, as planned in the chain of command, are also considered. The essential part of this phase is the determination of objectives and criteria to be used. Moreover, the formulation of possible action alternatives is required. A demanding step is the explicit evaluation of the impacts of each action alternative with respect to each criterion. The command and planning level models are typically different in their level of detail. Also, the action alternatives can be described in more detail on the lower-level model.

The composition of the group working on the model development can vary case by case. It can include general professionals in the application area as well as people belonging to the chain of command on the top levels. The direct participation of the commander is not necessary if she/he expresses the objectives of decision making by means of general instructions. However, it is likely that in most applications the commander will want to approve of the overall structure of the models developed.

In the decision analysis phase, the core task is the weighting of criteria of the MCDA models by the commander and the planning level actors. Depending on the problem area, the weighting can be carried out independently by them, but most likely there is a problem area specific support team involved as well. The decision analysis phase can also require professional assistance from decision analysis experts if the commander or the planning level actors are not well acquainted with working with the chosen MCDA model. It is also critical to be aware of possible cognitive biases which can be present in the weighting process. In practice, during the decision analysis phase, one would always include sensitivity analysis (see, e.g., Linkov et al. 2012). In our test case, we use a global sensitivity analysis approach based on interval modelling (Mustajoki et al. 2006).

On the command level, the commander gives the intention statement and the weights of the command level model based on the current decision-making situation. The expression of the intent and the criteria weights are transmitted to the planning level. On this level, an action plan is developed based on the intent and the evaluation of possible action alternatives using the command-level model. Moreover, weights of the planning level model are determined. The resulting plan and weights are used on the control level where implementable actions are identified and evaluated with the help of the planning level model. Finally, the actions are put into practice on the execution level. Each level always considers the evolution of the decision-making situation and adapts the decisions and their execution accordingly if needed. The perspective of how the actors on the different levels view the decision-making situation varies. On the command and planning levels, a strategic picture with a longer time horizon is likely to be addressed whereas the control and execution levels consider the more immediate situation with a shorter time horizon.

Level of Command	Organizational Unit	Main Command and Control Tasks
Level 0	Commander of the Air Operation	Expresses his/her intent on how to conduct the air operation
Level 1	Air Operation Center	Interprets the commander's intent Plans possible COAs for the air operation
Level 2	Control and Reporting Center	Interprets the commander's intent and the possible COAs Develops a detailed COA for the air operation Supervises the air operation
Level 3	Fighter Squadron	Converts the detailed COA into an executable plan Selects appropriate tactics, techniques and procedures and executes them in the air operation

FIGURE 2 | The organisational levels and units in the chain of command for air operations and the main command and control tasks at each level.

The chain of command depicted in Figure 1 does not include feedback between the levels. However, after the operation has been completed every organisation is likely to collect feedback from all levels ranging from the execution level to the command level. For clarity, we have not included this flow of information in the scheme in Figure 1 as it occurs only after the intention statement has been implemented. In evolving situations, there is also an implicit feedback loop from the execution level to the decision-making situation. The executed actions have an impact on how the situation develops in time as well as on the future plans and decisions in the command chain.

As far as the authors know, the use of MCDA for supporting communication, planning and decision making in a chain of command structure has not been suggested and tested in a practical case before. The use of the MCDA approach requires only a small additional effort and we believe that it most likely clarifies the decision situation to all actors on different levels of the command chain. In the following, we report results from the application of the MCDA approach in a military context where decision makers are dealing with critical life-and-death decisions in a highly complex, hostile, dynamic and time-critical environment found in air combat.

3 | The MCDA Approach in the Air Force Test Case

3.1 | The Chain of Command

Figure 2 depicts the chain of command structure used in the Finnish Air Force for planning and executing air operations. On Level 0, the commander of an air operation expresses her/his intent that describes the general idea of how the operation should be conducted and what its outcome should look like. The wording of the commander's intent is typically rather broad and it does not contain exact guidance for different levels in the chain of command about, for example, how aircraft and weapons systems should be used in the operation. The main goal of the intent is to ensure a common understanding of operation objectives, methods and capabilities throughout the command chain. Therefore, the intention statement must be interpreted correctly on the lower levels of the chain.

On Level 1, the staff of the air operation centre develop possible COAs based on the interpreted commander's intent. The commander's intent and the COAs provided by Level 1 are next interpreted on Level 2 where the staff of the control and reporting center select one COA and develop it into a more detailed one for Level 3, that is, fighter squadrons. The staff of Level 2 also supervises the operation when it is executed. Finally, on Level 3, the staff of the fighter squadrons convert the COA into an executable plan, select appropriate tactics, techniques and procedures and execute them during the operation following the commander's original intent and the COA directed by Level 2.

3.2 | Defensive Counter Air Operations

In the test case of the MCDA approach, we consider the planning and execution of a DCA operation. The purpose of such an operation is to detect, intercept and destroy enemy aircraft before they can inflict damage to friendly forces. DCA involves a range of activities including the interception of air targets and obtaining control of the air.

Fighter squadrons operate aircraft. A flight consists of four aircraft and is the standard fighting unit in air combat. In the test case, four flights are allocated for a DCA operation. Such an operation can be divided into three distinctive phases: ingress, attack and egress. In the ingress phase, the flights transit from the airbases to the combat area where the actual air combat, that is, the attack phase, is conducted and the selected COA is put into practice. In the egress phase, the flights withdraw from the combat and return to their airbases. We only focus on the planning of the attack stage.

3.3 | The Modelling Phase of the MCDA Approach

An MCDA model for supporting the planning of an air operation in the chain of command (see Figure 2) was developed in the modelling phase of the MCDA approach (see Figure 1). Compared to the generic MCDA approach, now only one model was constructed and the same model was used on Levels 0, 1 and 2 depicted in Figure 2. This practice was considered sufficient for the air force test case because similar COAs were addressed on Levels 1 and 2 of the command chain. The modelling phase was conducted following the principles of the value tree analysis with only one level of criteria. Overall values for the COAs were obtained with an additive value function model.

The purpose of the MCDA model was to support the selection of the final COA to be used by four flights during the attack phase of a DCA operation. It was assumed that both sides—friendly (i.e., own) and enemy—used typical fourth-generation fighter aircraft and their weapon systems. The model did not consider restrictions related to geography such as airspace limitations. Enemy aircraft were assumed to adhere to a predefined threat replication, but no detailed assumptions were made about their behaviour and combat tactics. The staff on different planning levels considered all these factors when planning the COA for the DCA operation. For the sake of simplicity, however, they were not explicitly included in the MCDA model.

3.3.1 | Objectives and Criteria

Typical objectives of a DCA operation were identified by first reviewing literature on the existing practices in modern air warfare. Based on the literature review, 10 candidates for objectives were shortlisted. Then, two air force commanders and a group of air warfare experts were interviewed. In this way, three key objectives were chosen to be used in the test case. The selected objectives were (i) minimise own losses, (ii) inflict losses on enemy aircraft and (iii) fight economically and minimise the expenditure of missiles.

One decision criterion for describing the accomplishment of each objective was identified. The criteria were

- *Survive*: Survival of friendly aircraft measured with the number of friendly aircraft lost during the operation.
- *Kill*: Destroyed enemy aircraft measured with the number of enemy aircraft lost during the operation.
- *Employ*: Expenditure of missiles measured with the number of air-to-air missiles launched by friendly aircraft during the operation.

After the identification of the objectives and the criteria, the commanders were asked whether they agreed with them or whether they would prefer some other objectives or criteria. Both commanders agreed with the objectives and the criteria suggested.

3.3.2 | Course of Action Alternatives

A COA alternative is defined by the following factors: the decision range, the missile launch range and the grouping of flights. The decision range determines the minimum acceptable distance between friendly and enemy aircraft. It indirectly defines the set of possible missile launch ranges from which a friendly aircraft can launch an air-to-air missile towards an enemy aircraft. That is, the smaller the decision range, the more there are possible missile launch opportunities and vice versa. The grouping of flights refers to the range between flights. This range dictates, for example, how well the flights can support each other during an operation.

When generating alternative COAs, three alternative decision ranges, missile launch ranges and ranges between the flights were considered. The COAs evaluated in the MCDA model were combinations of these ranges. Thus, one ended up in a high number of possible COAs although all the combinations were not feasible as some were tactically impractical. A total of 2041 COAs were formed.

3.3.3 | Evaluation of the COAs Under the Criteria

The evaluation of the COAs with respect to each criterion was carried out using criteria specific operational rules and value functions. The assessment was made by five air warfare experts with the assistance of a decision analysis expert. Each of the military experts had more than 10 years of experience in air warfare. The operational rules related to the number of missiles used and their launch ranges. The rules provided a ranking of all the 2041 COAs for each criterion. The rankings of the COAs were then converted into value scores using linear value functions. The linear form was found to be appropriate by the air warfare experts.

The evaluation process resulted in value scores reflecting the relative rankings of all the COAs under each of the criteria. These scores were used in the MCDA model when computing the COAs' overall values. The scoring approach can be challenged, but it was a practical feasible way of generating the value scores.

3.4 | The Decision Analysis Phase of the MCDA Approach

The MCDA model was programmed in the form of an MS Excel user interface that was linked to a Matlab model where the computations were conducted. The interface allowed for studying the overall values and rankings of COAs with different weighting methods. Moreover, the user interface enabled testing the sensitivity of COAs' values and rankings with respect to criteria weights applying an interval technique (Mustajoki et al. 2005, 2006).

In the decision analysis phase of the MCDA approach, the standard planning procedure discussed in Section 3.1 was used. The MCDA model was utilised to support the military staff's planning on Levels 0, 1 and 2 of the command chain (see Figure 2). In this MCDA-supported planning procedure, a commander provided weights of criteria in addition to a standard written intention statement on Level 0. The commander did the weighting so that it reflected her/his intent in the operation situation at hand. The commander's intention statement together with the weights was first sent to Level 1 where the MCDA model was employed in the planning of COAs and later to Level 2 where the final COA was selected and transmitted to a fighter squadron at Level 3.

4 | Testing the MCDA Approach in Simulated Air Operations

The MCDA approach was tested in two DCA operations. First, the same two commanders who were involved in the development of the MCDA model expressed their intents for these operations. Then, the COAs were generated following the standard and MCDA-supported planning procedures. The air operations were simulated using the COAs obtained with the two planning procedures. Both commanders were presented with the simulation results and they were asked to compare which of the COAs in each operation corresponded better to their original intention statements.

4.1 | Initial States of DCA Operations and Commanders' Briefings

The initial states of the two DCA air operations, Operations 1 and 2, were determined by two air warfare experts. The initial states outlined the overall goal of the friendly side that was to protect the airspace and a ground target. The goal of the enemy side was to achieve air superiority and destroy the friendly ground target. Moreover, the combat capabilities of both sides were defined.

The DCA operations were commanded by two persons, Commander A and Commander B, whose official duties included serving as the commander of air operations. Separate briefing sessions were organised for the commanders. In the briefings, the initial states of Operations 1 and 2 were introduced to the commanders. It was emphasised that these operations represented two separate and independent scenarios. In other words, whatever guidance the commanders would give for Operation 1 and whatever its outcome would be, that would not affect the initial state of Operation 2. In addition, the commanders were familiarised with the principles of the MCDA approach, the MCDA model and the alternative ways to assign criteria weights. Once the commanders were acquainted both with the initial states of the operations and the MCDA practices in the briefing, they expressed their intents and determined the weights of the criteria for Operations 1 and 2.

4.2 | Weighting of Criteria

The commanders used five weighting methods: SMARTER, that is, centroid weights based on ordinal ranking of criteria, Direct weighting, Swing weighting, SMART weighting and pairwise comparisons of AHP. These methods were selected for the evaluation because they are commonly used and conceptually simple to understand. Thus, they are realistic candidates for practical applications. For descriptions of these methods, see, for example, Belton and Stewart (2002). The reason for testing multiple weighting methods was because there is evidence in the literature that for behavioural and other reasons different methods do not necessarily produce similar weights (Pöyhönen and Hämäläinen 2001; Virtanen et al. 2022). The idea was to see if such differences would also emerge in our test case and what did the commanders think of the practical acceptability of the methods. After the commanders had assigned the weights, they were asked which weighting method they felt as the most meaningful and which was the most suitable one for describing their intents. The weightings were carried out on the Excel sheet developed for the test case. Its user interface was used to assign the weights using all five methods and to visualise the results of the weighting procedures.

The criteria weights determined by the commanders for the operations are shown in Tables 1 and 2. There were differences in the weights obtained with different methods. A positive observation was that the weights the commanders provided by different methods resulted in the same importance order for the criteria in both operations. A notable deviation was observed in the SMART and AHP weights of Commander B. This deviation can possibly be due to an error in applying the methods. In general, we cannot draw strong conclusions about the differences between the weighting procedures due to limited data from only two decision makers and the commanders did not practice by repeating the procedures either.

In the opinion of the commanders, the easiest weighting method to use was SMARTER which is natural since it only asks for a simple ranking of the importance of the criteria. The commanders were aware that this weighting method provides the least specific information on the relative importance differences between the criteria. The commanders felt that Direct weighting and Swing weighting were the most suitable methods and enabled them to describe their own preferences in the most appropriate way. In addition, the use of Direct and Swing weightings was perceived as simple and clear and they also produced relatively similar weights. Direct weighting is a straightforward procedure which does not explicitly refer to the ranges of criteria. Swing, on the other hand, considers the ranges explicitly. Perhaps the observation that the methods gave similar weights is only a finding related to our test case where the commanders were likely to have a good idea of the ranges of the criteria used and considered the ranges intuitively. The pairwise comparison process of AHP was not considered practical.

TABLE 1 | Criteria weights of Commanders A and B obtained with different weighting methods for Operation 1.

		Criteria weights		
Commander	**Method**	**Kill**	**Survive**	**Employ**
A	SMARTER	0.28	0.61	0.11
A	Direct	0.25	0.60	0.15
A	Swing	0.29	0.47	0.24
A	SMART	0.22	0.67	0.11
A	AHP	0.14	0.78	0.08
B	SMARTER	0.11	0.61	0.28
B	Direct	0.20	0.50	0.30
B	Swing	0.26	0.44	0.30
B	SMART	0.05	0.79	0.16
B	AHP	0.08	0.73	0.19

4.3 | Development of COAs

On the basis of the commanders' intents, COAs were developed for Operations 1 and 2. Two different COAs were formulated for both operations. Standard-COAs were based on the standard planning procedure utilising only the commanders' written intention statements. MCDA-COAs were constructed using the MCDA-supported planning procedure. On all levels of the command chain, the planning of COAs was conducted by air force staff officers responsible for such activities as a part of their daily duties. Different staff members were used for the development of the Standard- and MCDA-COAs.

The development of Standard-COAs was conducted according to the planning procedure discussed in Section 3.1. The planning of MCDA-COAs was carried out by following the same standard planning principles, but now the MCDA model with the criteria weights given by the commanders were also used. With the help of the MCDA model and the criteria weights, the staff on Level 1 were able to identify a set of COAs that satisfied the commander's intention statement. These MCDA-COAs, together with additional guidance on their execution, were transmitted to Level 2. On this level, the final MCDA-COA was constructed using the commander's intent, the guidance from Level 1 and the MCDA model. The resulting MCDA-COA was transmitted to Level 3, that is, to the fighter squadron, alongside with the necessary tactical details. Finally, the flight crews decided the appropriate tactics for the MCDA-COA with the exception of the missile launch and decision ranges as well as the range between the flights which were given as a part of the MCDA-COA.

TABLE 2 | Criteria weights of Commanders A and B obtained with different weighting methods for Operation 2.

Commander	Method	Criteria weights		
		Kill	Survive	Employ
A	SMARTER	0.11	0.61	0.28
A	Direct	0.10	0.65	0.25
A	Swing	0.16	0.53	0.31
A	SMART	0.05	0.63	0.32
A	AHP	0.05	0.72	0.23
B	SMARTER	0.11	0.61	0.28
B	Direct	0.20	0.50	0.30
B	Swing	0.23	0.45	0.32
B	SMART	0.04	0.77	0.19
B	AHP	0.10	0.71	0.19

As an example of the results given by the MCDA model, the five most preferred COAs obtained with different weighting methods in Operation 2 for Commander B are presented in Table 3. For simplicity, the COAs are characterised only with missile launch ranges for each flight. The preference orders of the MCDA-COAs were in line with the weights presented in Section 4.2. Overall, the best MCDA-COAs did not differ much although different weighting methods were used. For example, in the case of Commander B and Operation 2, the best COA (ID 1) was the same with all the methods. There were only small differences among the Top 5 COAs: in the most preferred COA all flights used a long (L) missile launch range whereas in the next four COAs one of the flights used a medium (M) missile launch range. Sensitivity analyses were also carried out where the weights were allowed to change in small intervals. The changes in the overall values and ranks of the best COAs were not considered critical. The details of the MCDA analysis are discussed in Kankaisto (2023).

The resulting Standard- and MCDA-COAs outlined plans for executing the attack phase of the DCA operations. There were differences between the COAs obtained with the standard and MCDA-supported planning procedures. The impacts of these differences on the operations were analysed through the simulation experiment discussed in the next section.

TABLE 3 | The five most preferred COAs obtained with different weighting methods in Operation 2 for Commander B.

Rank		SMARTER	Direct	Swing	SMART	AHP
#1	COA ID	1	1	1	1	1
		L, L, L, L	L, L, L, L	L, L, L, L	L, L, L, L	L, L, L, L
#2	COA ID	3	3	687	3	3
		L, L, L, M	L, L, L, M	M, L, L, L	L, L, L, M	L, L, L, M
#3	COA ID	15	687	99	15	15
		L, L, M, L	M, L, L, L	L, M, L, L	L, L, M, L	L, L, M, L
#4	COA ID	99	15	15	99	99
		L, M, L, L	L, L, M, L	L, L, M, L	L, M, L, L	L, M, L, L
#5	COA ID	687	99	3	687	687
		M, L, L, L	L, M, L, L	L, L, L, M	M, L, L, L	M, L, L, L

Note: L and M refer to long and medium missile launch ranges, respectively. For example, the notation L, M, L, L means that the missile launch range of the first flight of a group of four flights is long, the range of the second flight is medium and the range of the third and fourth flights is long.

4.4 | Evaluation of the COAs by Simulation

To evaluate how well the Standard- and MCDA-COAs corresponded to the commanders' intents, both operations were simulated. Participants of the simulation experiment included a fighter allocator, fighter controllers and flight leaders of four flights. The fighter allocator and the fighter controllers represented the staff of Level 2, whereas the flight leaders represented flight crews of Level 3. The fighter allocator's task was to supervise the fighter controllers, while each fighter controller supported her/his flight leader with tactical advice and directives. The flight leaders operated their own flights. All participants had at least 8 years of experience in their respective fields of expertise.

The simulation of the operations was conducted with the Modern Air Combat Environment (MACE) simulation system (Battlespace Simulations Inc. 2021). This system is used in the regular training of fighter allocators, fighter controllers and pilots as well as in the testing and evaluation of air combat tactics, techniques and procedures. The participants of the experiment were introduced to the simulation experiment and familiarised with the use of MACE. In addition, a training simulation run was carried out during which the participants were able to practice the control of friendly simulation entities in MACE.

In the simulations, the friendly force conducted DCA operations with four flights according to Standard-COAs and MCDA-COAs. The friendly entities were controlled by the flight leaders. The enemy was performing an offensive counter air operation. The enemy had both fighter-bombers and fighter aircraft as well as two ground-to-air missile systems. The number of enemy aircraft was 1.5 times that of the friendly aircraft. The behaviours of the enemy units were dictated by decision-making rules within MACE. The enemy's behaviour was fixed and the same in all simulations. However, the enemy behaviour changed reactively in relation to manoeuvres of the friendly aircraft.

As in real-world air combat, real time communication was enabled between the fighter allocator and the fighter controllers and between the fighter controllers and the flight leaders during simulations. A simulation run was paused at 30-s intervals. During that time, the flight leaders decided the control inputs for their flights. A snapshot of a simulation run is shown in Figure 3 where the friendly side has suffered one aircraft loss (blue explosion mark in the figure) and the enemy side four aircraft losses (red explosion marks in the figure). Each simulation run was terminated when all enemy aircraft were destroyed or simulation run time reached 60 min.

The simulations were recorded as videos and still images with an interval of 30 s. The recordings contained the positions of the friendly and enemy entities as well as the locations of destroyed aircraft. In addition to the recordings, the measures of effectiveness (MOEs) for aiding to understand the dynamics of an operation were computed. These MOEs were objective in the sense that they measured the combat success of friendly and enemy sides. They did not, however, directly describe how well COAs obeyed commanders' intents. The measures included numbers of own losses and destroyed enemy aircraft, a kill ratio, that is, the ratio of own and enemy losses and the consumption of missiles by the friendly force. Moreover, there was an indicator whether the friendly force was able to protect the ground target, that is, whether a DCA operation was accomplished. Video recordings, still images and MOEs were utilised when the commanders evaluated the COAs.

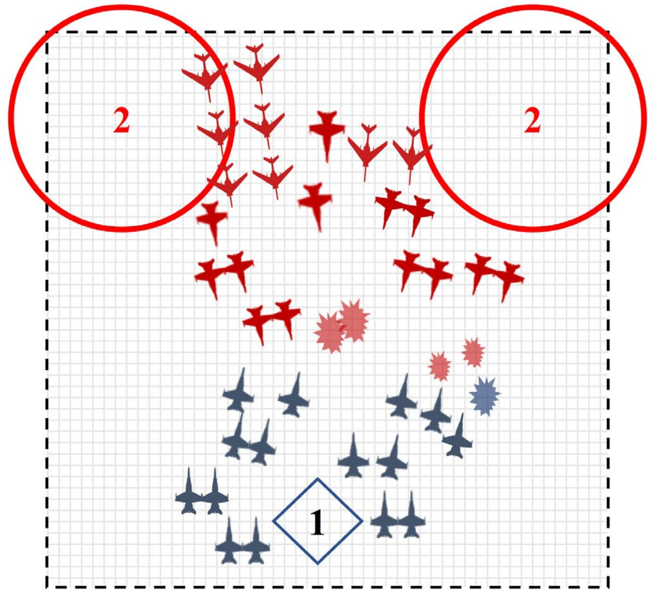

FIGURE 3 | A snapshot of a simulation run 10 min after the starting of the simulation. The red enemy side has two ground-based missile systems (red circles). The red fighter and bomber aircraft of the enemy side are directed towards the ground target (blue diamond) which is protected by the blue fighters of the friendly side conducting a DCA operation. The explosion marks indicate a missile hit to an aircraft.

4.5 | Comparison of Standard- and MCDA-COAs

The commanders compared the Standard- and MCDA-COAs in separate evaluation sessions. When the simulation results were introduced to the commanders, they were not informed of the planning procedure by which the COAs had been developed. First, the Standard- and MCDA-COAs were described for each operation. The values of the MOEs were also available. Then, the executions of Operation 1 with the Standard- and MCDA-COAs were presented simultaneously using the video recordings and still images of the simulations. Presenting the outcomes of the COAs concurrently allowed for a comparative evaluation. Operation 2 was briefed in the same way.

The values of the MOEs with the Standard- and MCDA-COAs are presented in Table 4. The DCA operation was completed successfully in all cases. The use of the MCDA-COAs led to better kill ratios than the use of the Standard-COAs in both operations. The missile consumption of the friendly side varied a lot between the COAs. However, the combined missile consumption was lower, that is, 82 when the MCDA-COAs were used compared to 105 with the Standard-COAs.

After studying the simulation results, the commanders were asked for their opinion on the execution of the operations. The commanders responded to two statements: ‘The execution of

TABLE 4 | The values of the MOEs in Operations 1 and 2 when the operations were executed with the Standard-COAs and the MCDA-COAs planned according to the intents of Commanders A and B.

	Commander A Operation 1		Commander B Operation 1		Commander A Operation 2		Commander B Operation 2	
COA	**Standard**	**MCDA**	**Standard**	**MCDA**	**Standard**	**MCDA**	**Standard**	**MCDA**
Enemy losses	8	24	21	12	24	12	7	12
Own losses	2	1	2	0	3	0	1	0
Kill ratio	1:4	1:24	1:10,5	1:12+	1:8	1:12+	1:7	1:12+
Consumption of own missiles	13	28	38	18	36	18	18	18
Accomplishment of operation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: A plus sign refers to a situation where there were no own losses.

air operation (1 or 2) was in accordance with my intent'. The answers were given on a five-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*totally agree*). The answers are presented in Table 5. The commanders pointed out that the assessment was based on various factors. Commander A focused on the importance of own losses and preserving resources, that is, avoiding unnecessary missile launches. As a result, he 'somewhat disagreed', that is, score 2, with the compliance in both operations when the Standard-COAs were used. He rated the compliance in the case of the MCDA-COAs in both operations to be equivalent to score 4 'somewhat agree'.

Commander B emphasised the importance of kills and avoiding own losses when analysing whether a COA followed his intent or not. The standard-COA obtained a compliance score of 3 'neither agree nor disagree' for Operation 1 and 2 'somewhat disagree' for Operation 2. He was satisfied with the implementation of both operations with the MCDA-COAs since he estimated the compliance in both cases to be equivalent to 5 'strongly agree'.

Overall, in the comparison of the COAs, the commanders clearly implied that the executions of the DCA operations using the MCDA-COAs were better aligned with the commanders' intents than when employing the Standard-COAs. Furthermore, the values of the MOEs suggested that the MCDA-COAs led to the better implementation of the DCA operations than the Standard-COAs. The results obtained in the test case supported our assumption that applying the MCDA approach can enhance communication, planning and decision making within a chain of command. While these observations were promising, they cannot be considered evidence of the approach's general applicability, as they were based on a single exploratory test case.

TABLE 5 | Assessments by Commanders A and B on the execution of Operations 1 and 2 using the Standard-COAs obtained with the standard planning procedure and the MCDA-COAs obtained with the MCDA-supported planning procedure in relation to the intents of the commanders.

The execution of air operation (1 or 2) was in accordance with my intent				
	Commander A		**Commander B**	
Planning procedure	**Standard**	**MCDA**	**Standard**	**MCDA**
Strongly disagree				
Somewhat disagree	1,2		2	
Neither agree nor disagree			1	
Somewhat agree		1,2		
Totally agree				1,2

5 | Discussion

The literature on the applications of MCDA is extensive. However, in most cases a decision situation studied is related to planning when there is time for deliberation and feedback. MCDA models are typically developed and used collaboratively with the relevant actors, that is, the problem owners and stakeholders. The chain of command decision-making situation is a novel context in MCDA literature and quite different from those previously considered. In the chain of command setting, not all actors need to, or even can, be involved in the development of an MCDA model. Instead, the model is developed at a higher command level and used by lower-level actors as a guideline for their decision making. The top-level commander does not participate in the use of the model or interact directly with lower-level actors, except for determining the model's criterion weights during operational decision making. This kind of situation is common in important fields such as emergency management and military operations. In many MCDA applications, the main benefits often relate to improved problem understanding and communication between stakeholders. Our new MCDA approach, utilised in the chain of command decision making, provides similar benefits by clarifying the overall goals of the operation as dictated by the commander to the actors in the chain.

We illustrated in the air force test case how MCDA can improve communication within the command chain by providing an enriched and easily understandable structure to the messages transmitted down the chain. Whenever people participate in the communication chain there is a risk that behavioural effects can distort the message. The new MCDA approach presented is one way of avoiding the possibility of producing distorted messages. In military applications, there can also be network structures within which the commander's intent needs to be communicated and then the communication challenges become even greater (Eisenberg et al. 2018).

One observation made in the air force test case of the MCDA approach was that different weighting methods can result in different weights. The same observation has been reported in earlier MCDA literature too (Pöyhönen and Hämäläinen 2001). We cannot tell whether reasons for this phenomenon stemmed from the methods themselves or from the cognitive challenges associated with their use and how decision makers understood them. To avoid this problem, one could practice more with decision makers in using the weighting methods. In the air force test case, we did not have time to test if more training would have made a difference. One should note that although the MCDA approach was new to the military staff attending the test, they all felt comfortable using it. Also, the use of the MCDA approach required only minimal adjustments to the planning procedure in use. The comparison of different weighting methods was included in the test case to gain practical insights into their usefulness when real decision makers use them in this specific context. The analysis was not intended as a comprehensive evaluation of the methods' performance in general. Nevertheless, this comparison contributes to the limited literature on the practical applicability of various weighting methods.

In MCDA, the decision maker needs to consider the ranges of criteria when giving weights. The fact that the commanders in our test case likely understood criteria ranges well does not guarantee that this would always be the case. This issue remains a challenge in applying the MCDA approach. For top-level decision makers to be able to provide criteria weights for related MCDA models, they need to have a good understanding of ranges of criteria.

The air force test case presented in this paper was exploratory in nature. While the results supported the potential applicability of the MCDA approach in the chain of command, several limitations prevented us from drawing general conclusions. The test case involved only one instance with two commanders in a specific operational domain and no random sampling of participants was conducted. The analysis did not consider geographic factors in the operation and assumed a fixed behavioural strategy for the enemy. Additionally, the value tree model was simple, non-linearities were not addressed and no comparisons with other MCDA methods were performed. Nevertheless, the positive results from this initial test motivate further research in other application domains and with alternative MCDA techniques. In general, demonstrating the applicability of new procedures in practice is challenging, as problems and situations are inherently unique, making it impossible to encompass all scenarios.

A straightforward continuation of the work reported in this paper would be to study how the MCDA approach could be applied in other areas and in other military settings as well. Emergency situations such as firefighting and rescue operations would be natural test problems (Gul et al. 2022; Gaievskyi et al. 2025). Incident command systems (Jensen and Thompson 2016) are used in emergencies. It would be interesting to study how to implement the MCDA approach in such systems and what would be potential benefits it could offer and challenges it might present in different situations. The value tree method used in this paper represents only one family of MCDA models. It would be valuable to investigate how methods from other model families, such as the PROMETHEE family (e.g., Brans et al. 1986), perform within this approach.

One could also think of a high-tech implementation of the MCDA approach. For example, there could be an automated decision support system which would produce data and value scores for action alternatives based on the evolving situation information possibly supported with a combat simulation model. In such a computerised system, one could even consider spatial criteria and related decision analysis methods (Harju et al. 2019). Moreover, the use of a simulation model would allow new ways to evaluate action alternatives by complementing decision criteria by measures related directly to the decision maker (Mansikka, Virtanen, Harris, et al. 2021). Such measures are situation awareness (e.g., Mansikka, Virtanen, Uggeldahl, eet al. 2021), mental workload (e.g., Mansikka et al. 2019) and normative performance (Mansikka, Virtanen, Mäkinen, et al. 2021). There could also be an automated procedure for the generation of action alternatives. Schadd et al. (2022) have even suggested using machine learning approaches to interpret written intention statements and to automatically generate measures for evaluating alternatives. However, the final weighting of criteria would always need to be carried out by commanders and planners. The primary benefits of applying the MCDA approach would be realised through its integration into existing planning platforms for air operations as well as command and control systems currently employed in operational settings. Additionally, such integrated tools could enhance the training of commanders and other personnel within the chain of command in operational planning processes, although the approach can already be used in its current form to support training.

6 | Conclusions

In this paper, we introduced a new MCDA approach to enhance communication, planning and decision making in a chain of command. The main contribution of the paper was the idea of communicating a commander's intent through the command chain using the criteria weights of an MCDA model, in addition to the traditional written expression of intent. The approach was tested in a realistic setting where air force commanders expressed their intents and air force staff officers created operation plans for DCA operations using the standard and MCDA-supported planning procedures. Our main conclusions from this test case were that (i) the MCDA approach was found applicable by the commanders and staff officers, (ii) it appeared to preserve the integrity of the command chain as the intent was consistently conveyed throughout the chain and (iii) it enabled the creation of acceptable and efficient plans for the operations. We note that the observations from the test case were not directly generalizable, as it considered only a single operation within the Finnish Air Force operational domain and relied on restrictive assumptions concerning, for example, enemy behaviour.

The commanders did not have problems in understanding and giving criteria weights of the MCDA model that reflected their intents. Also based on the verbal feedback, the face validity of the MCDA approach was found to be high among the participants of the test case. The executions of the operations planned with the MCDA approach were in better compliance with the commanders' original intents than those planned by following the standard planning procedure including only a written intention statement. The MCDA-supported operations also had better combat effectiveness.

The findings of the air force test case suggested that the MCDA approach helped to keep the commander's intent undistorted as it was passed through the chain of command. It aided in clarifying the ideas of the commander and offered a way to support the decision making of the actors on the different levels of the command chain. The approach might also be helpful in the training of military staff in a chain of command as it explicitly keeps the commander's objectives for an operation in focus. The test case also demonstrated the usefulness of simulation when studying decision behaviours in a dynamic environment. Recorded simulation runs allowed for an easy way of analysing time dependent consequences of decisions. Naturally, the results of this paper invite scholars to explore the application of the MCDA approach in other contexts and with alternative MCDA methods.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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